MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY Assistant Editor, BURTON M. VARNEY

Vol. 53, No. 11
W. B. No. 882

NOVEMBER, 1925

CLOSED JANUARY 4, 1926
ISSUED JANUARY 28, 1926

THE NORTH-POLAR COVER OF COLD AIR

PRELIMINARY RESULTS FROM THE MAUD EXPEDITION [1]

By H. U. SVERDRUP

In charge of scientific work of the expedition

It is a well-established fact that in mean latitudes the temperature of the air on a calm and clear day in winter is lowest close to the ground and increases with increasing altitude. With weak wind the same inversion may be found, but with strong wind the temperature generally decreases with altitude. The explanation is that the low winter temperatures of the air are brought about by cooling from below and by contact with the surface, which loses heat by radiation. On calm days, or days with very weak wind, a temperature inversion is thus generated, but with stronger wind the temperatures in the lower layers of the atmosphere are smoothed by the forced mixing caused by turbulence, and the normal decrease of temperature with altitude is established.

According to Simpson,[2] these conditions are very marked at the border of the Antarctic Continent. Simpson explains the great and rapid increase of the temperature at the surface, which every wind there brings as the result of the forced mixing of the lower layers. All temperature observations used by Simpson were obtained by balloons on calm days and show an inversion beginning at the ground, but the very rapid increase of temperature which accompanies every wind is evidence that the air becomes intermixed up to great altitudes by the wind.

Over the Polar Sea different conditions are encountered. Here every wind generally brings also an increase of temperature, which undoubtedly is due to the forced mixing of the air directly above the ice, but this mixing never reaches any great altitude and is generally confined to a layer of a thickness under 200 meters. In the present paper the temperatures will be discussed which were observed in the lower layers of the atmosphere over that part of the Polar Sea traversed by the *Maud* during the drift from August, 1922, to August, 1924.

The discussion will be confined to the results from the coldest months, November to March, which were spent during both years in about 75° north latitude and between 155° and 175° east longitude.

The change of temperature with altitude directly above the ice was determined by a resistance thermometer placed at the crow's nest 32 meters above the ice and read simultaneously six times daily with the readings of the thermometers in the meteorological screen 5 meters above the ice. The free-air temperatures were all determined by means of instruments carried by kites, and thus give information above the temperature-distribution during wind only. It must be emphasized here that all numerical values are preliminary and may be slightly changed by the final reduction of the observations.

According to the readings of the thermometer at the crow's nest, the temperature increases with altitude in winter during calm weather or weak winds. Selecting only the cases when "calm" was entered in the records and when the thermometers were read, it is found that the temperature at the crow's nest was higher than in the screen in 39 of 56 cases during the periods November to March. The mean values are: Screen, $t=-32.^{\circ}4$ C.; crow's nest, $t=-31.^{\circ}7$ C. During wind the temperature decreases generally in the first 50 to 200 meters above the ice, but this decrease is then followed by a very rapid increase. The first layer, where the temperature decreases, will be called the cold layer, and the second layer with rapid increase will be called the inversion layer. Above the latter the temperature generally increases slowly or remains constant to an altitude of 500 to 1,500 meters, where a new decrease begins. In the periods mentioned 66 kite ascents were made, but in six cases the altitudes reached were too low to reveal the characteristic features which have been described. In the remaining 60 cases the various layers were always well defined, and from the results of these ascents the following mean values have been derived:

Temperature at the ice, $-28.^{\circ}4$ C.
Thickness of cold layer, 136 meters.
Decrease of temperature within cold layer, $-0.^{\circ}5$ C.
Thickness of inversion layer, 136 meters.
Increase of temperature within inversion layer, $6.^{\circ}1$ C.
Temperature difference, $t_{1,000}-t_0$, $8.^{\circ}1$ C.
Temperature difference, $t_{1,500}-t_{1,000}$, $-1.^{\circ}4$ C.
Temperature difference, $2,000-t_{1,500}$, $-2.^{\circ}3$ C.

The last three differences have been derived from the ascents during which 1,000, 1,500, or 2,000 meters were reached. The mean velocity of the wind at the ice was 5.0 m/sec. The mean vertical distribution of the temperature with this wind velocity can, according to the above values, be represented by the following figures:

Altitude, (meters)	0	136	272	1,000	1,500	2,000
Temperature °C.)	$-28.^{\circ}4$	$-28.^{\circ}9$	$-22.^{\circ}8$	$-20.^{\circ}3$	$-21.^{\circ}7$	$-24.^{\circ}0$

In Figure 1 this mean temperature-distribution during wind in the cold season is represented graphically. The mean temperatures during calm weather are also entered in this figure by means of the broken line, supposing the temperatures above 272 meters to be the same. It may be remarked that the latter curve has exactly the same appearance as the mean curve obtained from five ascents with captive balloons during calm, cold weather at Cape Chelyuskin in 1910.

[1] Capt. Roald Amundsen's ship, the *Maud*, intentionally forced into the drift ice at Wrangel Island, drifted for two years with the ice fields north of the Siberian coast, and was icebound one year at Bear Islands, 800 miles west of Bering Strait.
[2] British Antarctic Expedition, 1910-1913, Meteorology. Vol. I, Discussion.

The increase of temperature with altitude in calm weather represents nothing unusual, but the characteristic feature met over the region of the Polar Sea here dealt with is that the mixing of the air by wind evidently does not reach great altitudes. The altitude up to which the temperature decreases represents the limit to which the air is intermixed, and the mean value of this altitude is only 136 meters. In 52 of 60 cases this altitude was less than 200 meters, and in no case more than 650 meters.

From the temperature observations alone it can, therefore, be concluded that no great exchange of air takes place between the cold layer directly over the ice and the warmer air above it, because such exchange should result in a smoothing of the temperatures, which never has been observed. This means that the cold layer close to the ice represents air which, to a great extent, is isolated from the free atmosphere.

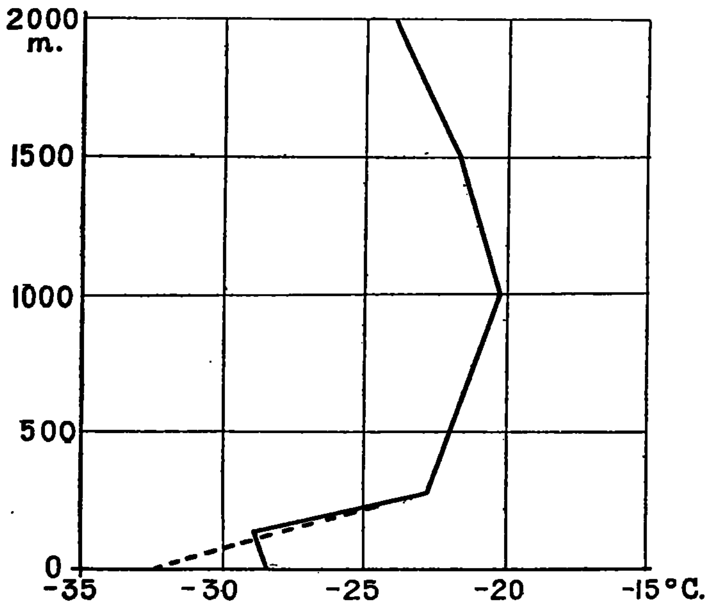

FIG. 1.—Mean temperatures, November to March
——— From kite ascents
– – – On calm days

The relations between wind velocity and temperature at the ice and the character of the cold layer have been examined by computing the following correlation factors:

Factor	$r_{v,m}$	$r_{v,t}$	$r_{v,\Delta t}$	$r_{t,m}$	$r_{t,\Delta t}$
Value	+0.40	+0.08	+0.15	+0.02	−0.33

The indices have the following meanings: v, wind velocity at the ice; m, thickness of cold layer; t, temperature at the ice; Δt, difference between the highest temperature observed above the inversion layer and temperature at the ice. This difference will be called the amount of the inversion.

The correlation between the wind velocity and the thickness of the cold layer is the largest, and the positive sign shows that the thickness of the cold layer generally increases with increasing velocity of the wind. This result is in agreement with the conception that the decrease of temperature within the cold layer is due to the forced mixing caused by the rough surface of the ice. With increasing wind this forced mixing increases, and the temperature decrease prevails to greater altitudes. These conditions are represented schematically in Figure 2, where the temperature above the inversion layer is supposed to remain constant and the branches 1, 2, and 3 represent the conditions during calm, moderate wind, and strong wind, respectively.

If the conditions were as simple as represented in this figure, it should be expected that (1) the temperature at the ice would increase with increasing velocity of the wind, (2) the amount of the inversion would decrease with increasing velocity of the wind, (3) the temperature at the ice would increase with increasing thickness of the cold layer, and (4) the amount of the inversion would decrease with increasing temperature at the ice. The various correlation factors have, according to the above compilation, all the expected signs, but are small, except the last. It may here be added that the correlation factor between wind velocity and temperature undoubtedly would be larger if it were to represent all conditions and not only the conditions during the kite ascents. In the present case the primary temperature increase due to the mixing (transition from 1 to 2 or 3 in fig. 2) does not enter.

The circumstance that only the last factor is so large that it may be regarded as representing an actual correlation, seems to indicate that this correlation is connected with conditions which hitherto have been left out of consideration, probably the duration of the wind. A small exchange of air probably takes place between the cold layer and the warmer air above. If the wind continues to blow during a long period, the other conditions remaining unaltered, the temperature of the cold layer must rise on account of this small exchange and the amount of the inversion consequently decrease. Thus a correlation between the named quantities is brought about which is independent of the velocity of the wind.

An examination of the cases in which kite ascents were made on consecutive days during which the direction of the wind was approximately the same, confirms this view. There are eight of these cases resulting from 16 ascents. In five cases the wind was increasing and in three decreasing, and it is found that increasing wind corresponds to increasing thickness of the cold layer and decreasing wind to decreasing thickness, but the temperature at the ice is generally higher on the second day and is independent of the change in thickness of the cold layer. This is evident from the following mean values:

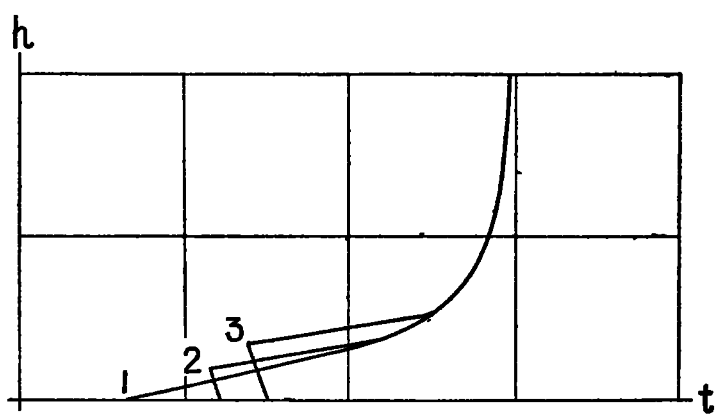

FIG. 2.—Effect of wind on vertical temperature distribution—1, during calm; 2, during moderate wind; 3, during strong wind

	Difference in wind velocity v_2-v_1	Difference in thickness m_2-m_1	t_2-t_1
	M/sec.	*Meters*	°*C.*
Wind increasing	+2.5	+105	+2.4
Wind decreasing	−3.2	−44	+3.3

From the results of the 16 ascents here considered, the following correlation factors have been computed:

Factor	$r_{v,m}$	$r_{v,t}$	$r_{v,\Delta t}$	$r_{t,m}$	$r_{t,\Delta t}$
Value	+0.80	+0.14	−0.15	+0.04	−0.65

As previously stated, only the first and the last are so large that they may be regarded as representing actual correlations. The first must be ascribed to the increased mixing which accompanies the stronger winds; the second, to the small exchange of air which takes place between the cold layer and the warmer air above. This exchange, however, never seems to be so large or to last so long that the air becomes intermixed to great altitudes and the cold layer disappears, because such conditions have not been observed.

The conclusions regarding the exchange of air between the various layers are confirmed by a study of the change of wind direction and velocity with altitude. The wind observations from the free atmosphere were obtained by means of pilot balloons after the one-theodolite method. This method is not entirely satisfactory, particularly for a study of the wind close to the ground, but, as the results from the pilot balloons were in perfect agreement with the experiences regarding the wind conditions gained during the kite ascents, they can be regarded as trustworthy. The simultaneous changes in temperature and wind were studied from several cases in which a pilot balloon was observed shortly before or after a kite ascent.

It is generally found that the wind velocity increases slowly in the lower part of the cold layer and that the direction turns slowly to the right. At the boundary between the cold layer and the inversion layer there is a very rapid increase of the wind velocity and a rapid turning of direction to the right. The velocity generally reaches a maximum within the inversion layer, and above this the velocity as well as the direction of the wind, remains constant, on the average, through several hundred meters.

The cases in which the wind and the temperature-changes were observed practically simultaneously have been divided into two groups according to the thickness of the cold layer, the first containing the cases in which this thickness was less than 100 meters and the second those in which it was between 100 and 200 meters. The mean values of temperature, wind velocity, and turning of wind direction referred to the direction at the ice are entered for various altitudes in Table 1 and represented graphically in Figure 3.

TABLE 1.—*Summary of temperatures (t) and wind velocities (v) for observations at different altitudes (h)*

Group I, altitude less than 100 meters (11 cases)					Group II, altitude 100 to 200 meters (8 cases)				
Temperature		Wind velocity			Temperature		Wind velocity		
h	t	h	v	δ	h	t	h	v	δ
Meters	° *C.*	*Meters*	*M./sec.*	°	*Meters*	° *C.*	*Meters*	*M./sec.*	°
0	−32.0	0	4.7	0	0	−29.2	0	5.5	0
66	−32.0	0–160	10.1	23	153	−29.7	0–150	8.5	16
200	−23.8	160–310	11.3	35	270	−21.9	150–300	13.6	38
560	−21.0	310–470	11.0	36	520	−20.1	300–450	13.4	42
810	−20.7	470–620	10.2	35	980	−19.1	450–600	14.1	38
		620–770	9.6	34			600–750	14.1	38

From Figure 3 it is seen that the changes in temperature and wind within each group have the characteristic features which were described above. The inversion layer, which has been set off in the figure, acts evidently as a sliding surface below which the wind velocities are small on account of the resistance offered by the rough surface of the ice and above which the wind has the character of gradient wind. This circumstance alone is evidence that no considerable exchange of air takes place between the lower cold air and the upper warmer air.

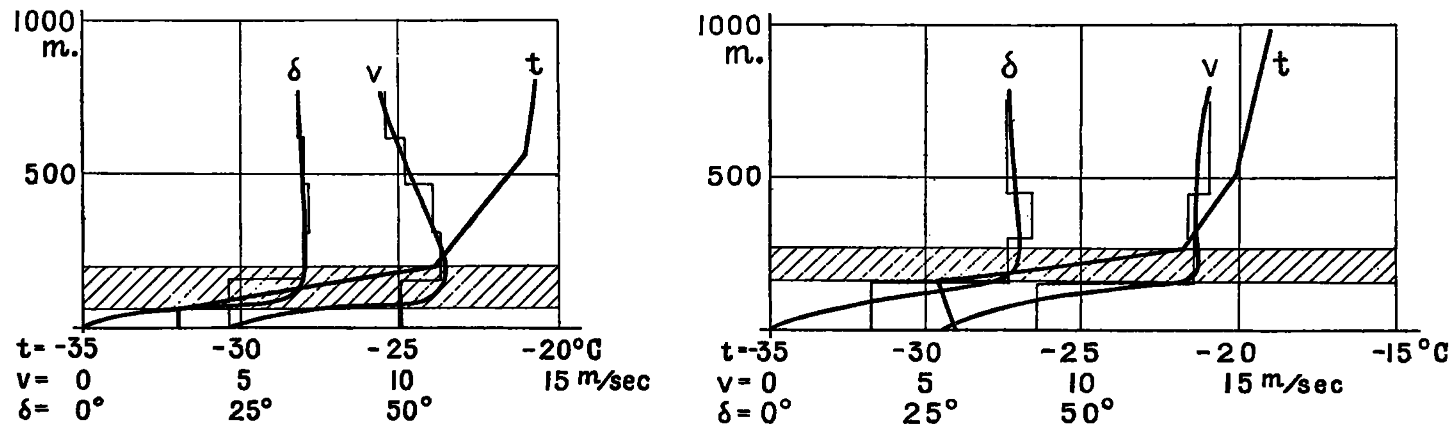

FIG. 3.—Mean values of temperature and wind. Left: Thickness of cold layer less than 100 m. Right: Thickness of cold layer 100 to 200 m.

The exchange of mass between the various layers can, however, be examined more closely by a study of the turbulence. It is well established that the change of the wind with altitude in the vicinity of the ground depends upon the turbulence, for which the coefficient of turbulence is a measure. This coefficient is proportional to the mass of air which per square and time unit is exchanged between two adjacent layers, and thus gives direct information regarding the quantity in which we are interested at present. Hesselberg [1] has developed formulas which permit computation of the coefficient of turbulence from the change of the wind with altitude supposing either the barometric gradient or the gradient wind is known. In the present cases the wind at 500 meters may be regarded as representing the gradient wind, and the coefficient of turbulence can thus be computed by means of the data contained in Table 1. The following mean coefficients have been found within the two groups for the cold layer and the inversion layer; for sake of comparison, the corresponding value for the layer 0 to 500 meters derived from observations from Central Europe [2] has been added.

[1] Über die innere Reibung in der Atmosphäre. *Ann. Hydrogr.*, Berlin, v. 47, 1919 (105–119).

[2] Hesselberg and Sverdrup. Die Reibung in der Atmosphäre. *Veröff. d. Geophys Inst.*, Leipzig, I.

	Group I		Group II		Central Europe
	Cold layer	Inversion layer	Cold layer	Inversion layer	0-500
Coefficient of turbulence, η	C. g. s. 30	C. g. s. 4	C. g. s. 100	C. g. s. 4	C. g. s. 50

From the above it is seen that the coefficient of turbulence is greater within the cold layer, where the value is of the same order of magnitude as found over land in mean latitudes, but within the inversion layer the coefficient in both cases has only one-tenth of the normal value. According to this result, no great exchange of air can take place between the cold layer and the upper warmer air.

The observations with pilot balloons were far more numerous than the kite ascents, and according to them the change of wind with altitude has always the same character if the velocity at the ice is greater than 3 to 4 m./sec. The turbulence, that is, the exchange of air, therefore must have generally the character which was found above, and the wind observations thus confirm the conclusion which was drawn from the temperature observations only.

Our results apply directly to the vertical temperature distribution over the region of the Polar Sea between 155° and 175° east longitude and in 75° north latitude, but there are reasons for believing that the same conditions are typical over the whole Polar Sea. Grouping the results of the kite ascents according to the direction of the wind at the ice, we obtain the values given in Table 2.

TABLE 2.—*Characteristics of cold layer for various wind directions*

Characteristic	Wind from—			
	NW.-NE.	NE.-SE.	SE.-SW.	SW.-NW.
Thickness of cold layer	156	120	131	166
Amount of inversion	+6°.4	+9°.4	+6°.4	+5°.6
Mean wind velocity at ice	4.6	5.1	4.8	5.4
Mean temperature at ice	−28.0	−28.3	−28.6	−29.3

The thickness of the cold layer is smallest during easterly winds, when the amount of the inversion is greatest. As the mean wind velocity and temperature at the ice are approximately the same in all groups, this result is practically independent of the correlations previously found.

The fact of greatest interest at present is, however, that the character of the vertical temperature distribution is independent of the direction from which the wind blows, and this is evidence that the same conditions prevail over wide areas. This is confirmed by the results of several ascents with captive balloons and kites performed at Cape Chelyuskin (77° 32′ north latitude, 105° 40′ east longitude) in the spring of 1919, and by the results of kite ascents made during the winter 1924–25 off Bear Islands (70° 43′ north latitude, 162° 25′ east longitude), which all show the same features. Considering the uniform character of the meteorological conditions over the Polar Sea, it seems justified, therefore, to draw the final conclusion that the whole Polar Sea in winter is covered by a thin layer of cold air which, to a great extent, is isolated from the warmer air above. In calm weather or during weak winds the temperature above the ice increases rapidly with altitude because the air is cooled from below. Under these conditions there is no definite transition from the cold to the warmer air, and no exchange of mass takes place between the cold air at the ice and the warmer air above. During stronger winds the cold air is intermixed, and the temperature decreases to an altitude which generally increases with increasing velocity of the wind but seldom surpasses 200 meters. The cold air is then separated from the warmer air above by a sharp layer of inversion through which a small exchange of air takes place.

The temperature distribution during wind, which has been described here, can prevail over a vast plain like the Polar Sea, but not over a continent, where the differences in elevation cause forced vertical movements which finally must result in a complete smoothing of the temperatures in the lower part of the atmosphere and the

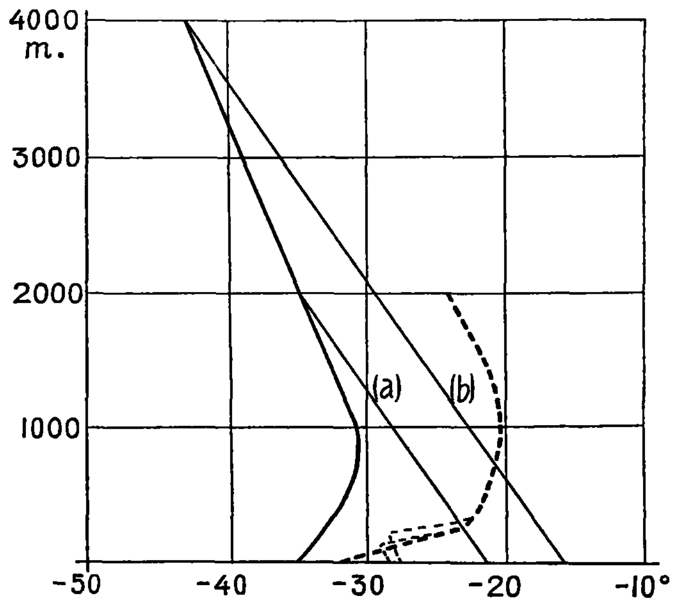

FIG. 4.————— Effect of wind on temperature distribution in the Antarctic (Simpson). — — — — Effect of wind on temperature distribution over the Polar Sea (*Maud* Expedition)

disappearance of the cold layer developed on calm days. This effect of the wind, which explains the conditions observed at the borders of the Antarctic Continent, has been illustrated by Simpson in a figure which has been reproduced in Figure 4. The thick curve represents the vertical temperature distribution during cold, calm weather as found by balloon observations from Cape Evans, curves (a) and (b) representing the assumed temperature distributions during moderate and strong winds. For comparison, curves 1 and 2, representing the mean temperatures during calm and during a wind of 5 m./sec. over the part of the Polar Sea traversed by the *Maud*, have been entered as broken lines. The different character of the conditions above the Antarctic Continent and the Polar Sea is evident.

We have here dealt only with the conditions in winter. The cold layer over the Polar Sea is, however, developed in the fall and prevails during the greater part of the spring, thus existing through the major part of the year. In July and August a corresponding layer of cold air is developed, at least over the region traversed by the *Maud* and south of it. In these months the ice is melting and the temperature of the air directly above the ice can, therefore, never deviate considerably from 0° C., but above an altitude of 150 to 200 meters the mean temperature according to the kite ascents seems to be higher, partly on account of convection and partly perhaps on account of direct absorption.

A consequence of these conditions is that a number of the meteorological elements observed at the ice show periodic and unperiodic changes which are of a very local character because they take place within the cold layer directly above the ice. This circumstance seems to be of fundamental importance for the understanding of many of the meteorological conditions over the Polar Sea, and will be taken into account in the fuller discussion of the meteorological observations of the expedition.

METEOROLOGICAL CONDITIONS IN THE EURASIAN SECTOR OF THE ARCTIC

[A summary of the data and conclusions presented by Karl Schneider, A. Berson, L. Breitfuss, M. Robitzsch, R. Süring, A. Wegener, and K. Wegener, in "The airship as a means of exploration in the Arctic." [1]]

By BURTON M. VARNEY

[Weather Bureau, Washington, D. C., November, 1925]

It is perhaps not widely known in this country that an organization called the International Society for the Study of Arctic Exploration by Means of Airships is actively engaged in working toward a solution of this problem. It is composed of some 80 European scientists, including leading meteorologists, oceanographers, geographers, geologists, and polar explorers. Dr. Fridtjof Nansen is its president. There were, at the time the memoir here summarized was published (October, 1924), one American member and no English.

The problem of air navigation in the Arctic is essentially a meteorological one. Hence some 18 pages of the 60-page memoir are devoted to summarizing the pertinent available meteorological data, with special reference to the Asiatic sector. Cloudiness and fog, and wind directions, together with the controls over them, receive major attention.

Cloudiness and fog.—For the area north of 80° the only cloud data are from the traverse of the *Fram* in 1893–1896 from near the mouth of the Lena River to Tromsö in northern Scandinavia. The mean values are set out in Table 1. They indicate clearly a summer maximum of cloudiness, and the fact that the period of the long night had somewhat less than half of the summer amount of cloudiness.

Fog, while showing a summer maximum, was nevertheless nearly absent throughout the autumn, winter, and spring.

TABLE 1

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
					Cloudiness (1-10)							
3.7	4.4	5.6	5.7	7.2	8.5	8.8	8.8	8.2	6.4	4.4	3.7	6.2
					Days with fog							
0	0	2	1	2	10	20	16	10	5	1	0	67

The intensity of development of clouds, fog, and precipitation * * * is, for the polar regions proper, very limited. According to the *Fram* observations the monthly amounts of precipitation were about 3 mm., although in one exceptional case in July there was a fall of 20 mm. in a day. * * * There is no month without snowfall. Rain falls mostly from May to September only, in any case in those areas which lie far from the open sea. The snow cover grows during the course of the winter to a very heavy mass through the condensation of atmospheric moisture on its surface, the temperature of which is mostly below that of the air. This form of precipitation it is not possible to measure. Rime and hoarfrost, on the other hand, while found on a few days, in general are observed only in limited quantity and in regions near the sea. Hoarfrost as we observe it in Europe, is to be classed among the rarities in the Arctic, because the water content of the atmosphere, on account of the low temperature, is so much smaller. The danger of an ice deposit on a traveling airship is therefore less likely than in Europe. An airship journey in the Arctic summer seems, therefore, as far as the meteorological factors are concerned, not seriously more difficult than a similar trip in the European winter.

[1] Published by the Internationalen Studiengesellschaft zur Erforschung der Arktis mit dem Luftschiff, Oct. 7, 1924. (Copy received by the U. S. Weather Bureau Library from the Gesellschaft für Erdkunde, Berlin.)

For the border region of the Arctic in the Eurasian sector, cloudiness data are presented in Table 2 (Franz Josef Land and Spitzbergen), and in the large table at the end of this paper appear data for the five months March–July at 19 stations covering various periods (mostly less than 5 years) from 1 to 33 years. The distribution of these stations is shown in Figure 1.

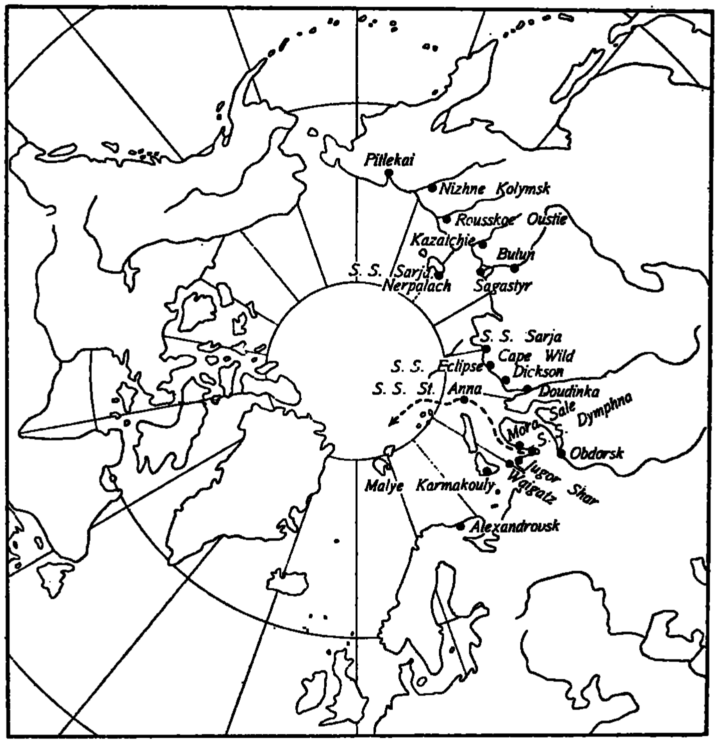

FIG. 1.—Stations represented by data in Table 8.

TABLE 2

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
					Franz Josef Land							
5.2	5.2	5.3	5.8	7.4	8.2	8.1	8.0	8.0	7.2	5.9	5.1	6.6
					Spitzbergen							
6.4	6.3	6.1	6.6	7.3	7.8	8.0	7.9	7.8	7.8	6.9	6.1	7.3

So far as cloudiness is concerned, Franz Josef Land and Spitzbergen are dreariest in summer, with little to choose between them. In midwinter, however, while cloudiness at Franz Josef Land has declined to about 5, at Spitzbergen, nearer the open sea, it has decreased only to 6. These data are for cloudiness without respect to altitude of the clouds. At Dickson Harbor, in longitude